Vocal Acoustics and the *Messa Di Voce*

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ABSTRACT

This paper examines the historical development of the *messa di voce,* a simple crescendo-decrescendo on a single pitch. The *messa di voce* demands technical control over breath energy, glottal resistance, vocal tract modulations, and acoustic events. A study was conducted to examine the spectral balance in the voices of four professional opera singers as each performed a series of *messa di voci* in three distinct vocal registers. Employing an easy-to-use mobile phone application, spectrograms of each sample were produced and analyzed for the frequency modulations of the vocal tract, revealing common acoustic strategies for negotiating the exercise. This project proposes that spectrographic analysis can accelerate progress toward technical mastery of the vocal instrument.

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Introduction

The hallmark of the classically trained singer is the illusion of a seamless voice capable of singing on an endless supply of breath. To accomplish this there must be a balance of forces among the intrinsic and extrinsic musculature of the larynx, the hearing mechanism, and the posture and support systems, all of which directly affect registration events and breath management. The *messa di voce* (hereafter MDV) is the classic test of this skill. It is a simple crescendo-decrescendo on a single breath. However, there is historically some debate over the particulars of the MDV, such as how to perform it and when to introduce it into one's training. Recently, voice science has helped to quantify some parameters for evaluation and provide factual data. Current development and application of select technologies continue to expand research and provide visual images of vocal function. This paper examines recently published research in the area of voice science and surveys the historical and contemporary vocal pedagogy literature. A study was conducted to examine the spectral balance in the voices of four professional opera singers as each performed a series of *messa di voci* in three distinct vocal registers. Samples were taken of each singer performing two distinct methods of MDV. The resultant spectrograms were analyzed for the balance of resonance frequencies within the vocal tracts. Power spectra were observed from specific points in the spectrogram to explore visible evidence of onset and release of the tone, strength of the singer's formant cluster, and spectral wash or frequency intensity across the available spectrum. Comparisons were made between the two approaches to determine their effect on the resonances of the vocal tract. These effects determine the quality of the tone and affect the physiological manner of its production.

Evolution of the Singing Voice

The human voice is a unique evolutionary marvel. Its basic anatomical function as a valve to prevent foreign objects from entering the lungs is shared with all our relative ancestry. However, no other species has control over such an extensive range of fundamental frequency, harmonic color, or variable dynamics in vocalism. Much of this can be attributed to the apparent arbitrary appearance of bipedalism among our ancestors, which altered the structural design of the throat. As our predecessors shifted to walking upright, the spinal cord repositioned itself in relation to the skull and now entered the skull from below rather than from behind. This greatly reduced the space for the larynx between the mouth and the spinal cord. Consequently, the larynx was forced to establish a functional position lower in the throat. This evolutionary lengthening of the vocal tract, coupled with increased space and flexibility in the pharyngeal and buccal cavities, created a potential for a more diverse range of vocalization.[1] This lengthening also contributes to the ability to establish and maintain a specific 1:6 ratio or less of the size of the laryngeal outlet to the size of the oropharynx.[2] According to many contemporary voice scientists, this relationship is essential to a spike in the intensity of resonance frequencies around 3000Hz. Here lies the so-called "singer's formant cluster," an element of a well-balanced and functional vocal production, with the potential to project over a

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[1] Leslie C. Aiello, "Terrestriality, Bipedalism, and the Origin of Language." in *Evolution in Social Behavior Patterns in Primates and Man*, ed. W.G. Runciman, J. Maynard-Smith, and R.I.M. Dunbar (Oxford: Oxford University Press, 1996), 272.
[2] Gunnar Fant, *Acoustic Theory of Speech Production* (Haag: Mouton, 1960), 267.

large orchestra. The material composition of the larynx itself has also evolved with bipedal anatomy. The thick, cartilaginous larynx and vocal folds of the primate has evolved into the pliable, membranous one of the modern human, resulting in a transmutation from a harsh sounding primal screech to a supple soothing vocalism. These dramatic physiological changes to the laryngeal structure are coupled with the potential relaxation of the selective pressure applied by the thoracic muscularity to the valvular larynx. Gone is the need for high pressure chest stabilization necessary for knuckle-walking or climbing, and the thorax sheds some of its weighty muscularity in exchange for a novel capacity for suppleness and flexibility. The ear has had an evolution of its own. The composition of our ancestor's ear lent itself to greater sensitivity of high-frequency sounds than that of our closer relative the Neanderthal, whose otic composition greatly resembles our own.[3] The great cultural achievements of the Neanderthal can be explained by the availability of a vastly expanded range of vocal gestures able to be both produced and heard: "(T)he Neanderthals' enhanced motor control over the tongue and breathing, and their auditory capacity matching that of modern humans, are best explained as having been specifically selected by evolution for vocal communication."[4]

So armed with a broader range of vocal sound and a diverse palette of expressivity brought upon by these physiological changes, our early *Homo* ancestors developed a particular social vocal grooming. This evolution complemented the established indispensable act of social physical grooming, creating and instilling stronger common bonding among social groups. This additional means of connecting with others

[3] Jacobo Moggi-Cecchi and Mark Collard, "A Fossil Stapes from Stekfontein, South Africa, and the Hearing Capabilities of Early Hominids," *Journal of Human Evolution* 42 (2002): 259-265.
[4] Steven Mithen, *The Singing Neanderthals* (Cambridge, MA: Harvard University Press, 2006), 227.

had the potential to reach a greater number of individuals and therefore create larger and stronger communities. Researchers believe these early communications were more closely related to music than language, involving patterns more rhythmic and melodic than articulatory and also strongly connected to gesture and movement.[5] Thus there exists the patent need to communicate in a manner that is expressive and physical, engendering unique auditory response from the listener, and rooted in the essence of humanity's evolution. This communication is centered upon the relationship between the human voice and the ear. It is necessary to trace the journey from socializing on the savannah to *bel canto* is to find the constant through it all, the relationship between the musical instrument every human being carries within, i.e. the voice, pairing with the intricate actions of the attentive ear.

Early writings on the *Messa di Voce*

Constant in the voice is a natural rise and fall measured by changes in air pressure which activate the receptive cilia within the ear. In a healthy ear, these vibrations are transmuted by the cochlear integrator within the inner ear. They travel first to the thalamus and then to the cortex, the pons, the cerebellum, and back to the thalamus. This creates a constant feedback loop which is used by the vocalist, i.e. singer or speaker, to monitor and adjust vocal function to produce a predetermined ideal tone. There is a natural and regular rise and fall in sound pressure level to create a specific vibratory frequency, a natural rise and fall in transglottal airflow, and a natural rise and fall that is related to inflection and reflected in the metrical patterns of speech. This is all mirrored in

[5] Ibid., 143-159.

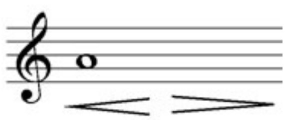
the organization of musical sounds, working either with or against this natural ebb and flow. For the elite singing voice, the full expression of its natural beauty and capabilities are made manifest in the flexible sustaining of a vocal tone that excites the ear, and in the ability to directly communicate through inflection, the subtleties of a particular language. These are the touchstones for every *bel canto* singer. This idea was first widely disseminated at the dawn of the seventeenth century by Giulio Caccini in his *Le nuove musiche*, wherein as introduction, he promotes *The New Music.* Conveniently, he also provides examples which he himself composed, in order to recapture the oratorical delivery of the ancient Greeks who were lauded as the ideal of classical culture.[6] For the perspicacious scholar, he even provides the essence of the quintessentially Baroque notion of *sprezzatura*, or nonchalance, wherein the singer must *"crescere e scemare la voce*" (increase and decline the voice) in order to give life and energy to the musical phrase.[7] The ability to increase and decrease the sound pressure level at will is an indispensable element in the performance of music from the Baroque era, where utmost importance is paid to elements of expression and where gradations of loudness and intensity are only limited by the abilities of the singer. This simple idiomatic turn of phrase would evolve into a technical tool to outfit a well-equipped singer of the eighteenth and early nineteenth centuries, and it became a patent measure of proficiency by which to judge the expertise of that singer.

This simple gradation from soft to loud and back became widely known as the *messa di voce.* The term first appeared in writing in *Opinioni de' cantori antichi, e moderni o sieno osservazioni sopra il canto figurato* by Pier Francesco Tosi, a castrato

[6] Giulio Caccini, *Le Nuove Musiche*, trans. H. Wiley Hitchcock (Madison, WI: A-R Editions, 1970), 6.
[7] Ibid., 14.

singer, composer, and writer on music. First published in Bologna in 1723, it is believed to be the first full-length treatise on singing. Somewhat in the manner of his predecessor Giulio Caccini, Tosi rails against the florid excesses of his contemporaries. As an antidote, he provides the singing teacher and aspiring professional singer with an instructional guide to unite the chest and head registers (a new concept, as previous authors emphasized the necessity to sing only in one's natural voice), and theorizes on appropriate interpretive devices such as the *messa di voce* (**Figure 1**), which "consists in letting (the voice) come out softly from the least *piano*, so that it goes little by little to the greatest *forte*, and then returns by the same artifice from the *forte* to the *piano*."[8]

Figure 1: *Messa di voce.*



The student's first lesson is to produce a single tone with the greatest expanse of color. The earliest mentions of the gesture are always accompanied with instructions to control the breath. As the castrato singer, voice teacher, and writer on the subject of singing, Giambattista Mancini wrote in 1774 in his vocal manual *Pensieri e riflessioni pratiche sopra il canto figurato*: "The most necessary thing for success, is the art of knowing how to conserve the breath, and manage it."[9] And a true artist is skilled at "the art of conserving, reinforcing, and taking back the breath since on this alone depends the

[8] Pierfrancesco Tosi, *Opinions of Singers Ancient and Modern*, trans. Edward Foreman (Minneapolis: Pro Musica Press, 1986), 17.
[9] Giambattista Mancini, *Practical Reflections on the Art of Florid Song*, trans. and ed. Edward Foreman (Champaign, IL: Pro Musica Press, 1967), 62.

gift of the just and necessary gradation of the voice."[10] The "gradation of the voice" referred to the amplitude and density of vocal production. And in 1792 Jean-Paul-Égide Martini penned this precursor to the modern concept of breath management, which in the nineteenth century and in current voice studios became identified by the Italian term *appoggio*, the nominative from of the verb *appoggiare,* meaning to lay something down upon something else: "When upon respiration, the lungs are filled with air, it is necessary to hold back the air with greatest care and not let anything be expelled other than the portion required to make the vocal chords (*sic*) vibrate. This manner of breathing gives the strength to swell and diminish the tones at will."[11] This linking of breath to tone is the essential balancing act for the *bel canto* trained singer. The concept of *appoggio* encourages the singer to allow the voice to ride upon the breath rather than have the diffused breath pass through the voice. This control over breath flow is necessary for the highly intricate balancing of the MDV.

Manuel Garcia II

The nineteenth century methods absorbed those of the previous generation while providing more detailed instruction, including actual exercises for the voice. The *messa di voce* exercise takes pride of place as the first lesson in many of the vocal tutors of the early years of the century.[12] In 1830 French composer, educator, and head of the voice department at the Paris Conservatory, Alexis de Garaudé wrote in his *Methode Complète*

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[10] Ibid., 45.
[11] Sally Sanford, "Seventeenth and Eighteenth CenturyVocal Style and Technique" (PhD diss., Stanford University, 1979), 90.
[12] See especially Giuseppe Aprile, *The Modern Italian Method of Singing* (London: Robert Birchall, 1795); Domenico Corri, *The Singer's Preceptor* (London: Chappell, 1810); Anna Maria Pellegrini Celoni, *Grammatica, o siano regole di ben cantare* (Leipzig: Peters, 1810); Isaac Nathan, *Musurgia Vocalis* (London: Fentum, 1836).

des Chants regarding the execution of the MDV that the student must onset quickly and accurately, with no breath noise. He advises that each tone be spun (French –"*file*"). He also warns that no matter how softly you begin the tone, as you crescendo, your register must not change.[13] Garaudé was a student of one of the last great castrati, Girolamo Crescentini, and echoes many of that great master's thoughts on the MDV. Both stress the value of the device and urge its use, not only across periods and phrase lengths but even on individual notes.[14] This final idea runs contrary to the modern view of equal force applied to each tone, but there is no denying that the ability to do so at will requires an inordinate measure of skill.

A significantly different description of the technique is provided by Manuel Garcia II, his colleague at the Conservatory, in the revised edition of his *Traité complet de l'art du chant* in 1847:

> The student will begin the tone softly and in the falsetto and in somber timbre…. Then without varying the position, and, as a result, the timbre, one will pass into the chest register. Once in the chest register, one will raise the larynx again and will dilate the pharynx to clarify the timbre in such a way that toward the middle of the duration of the tone it will have all its brilliance and all its force. In order to soften the tone, the student will do the reverse; that is to say that before passing into the falsetto register, at the moment the voice is diminished, he will darken the chest tone, again fastening the larynx low.[15]

These are the words of arguably the most famous voice teacher of all time. The son of one of Gioacchino Rossini's favorite tenors, the elder Manuel, and the brother of Maria Malibran and Pauline Viardot, Garcia II turned to teaching after a brief and failed attempt at a singing career. This treatise was published seven years before his famous use of the

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[13] Jeanne Roudet, et.al., *Chant: Les grandes méthodes romantiques de chant* (Courlay, France: Editions Fuzeau, 2005), 128.
[14] Ibid., 12.
[15] Manuel Garcia II, *A Complete Treatise on the Art of Singing: Part One*, ed. and trans. Donald V. Pashcke (New York: Da Capo Press, 1984), 135-136.

newly invented laryngoscope to view the action of the glottis during phonation. His laryngopscopic observations confirmed his theories on phonation and registration. Garcia's method for the MDV involves a finely tuned balance between vibratory function at the glottis, laryngeal depth and breath flow. His MDV begins softly in falsetto. The larynx is held low to darken the timbre. Increased breath flow, balanced by a corresponding firmer resistance at the glottis, induces more chest voice and is coupled with laryngeal elevation and a pharyngeal adjustment that creates a brilliant quality. Laryngeal descent darkens the vocal timbre, and a loosening of glottal resistance coupled with a decrease in breath flow begins the decrescendo. The MDV therefore demands delicate tuning of vocal fold closure, management of breath pressure, and judicious control of laryngeal depth, progressing through the entire expressive palette of the voice. According to Garcia, the singer can employ the entire range of color, quality, and intensity on a single note. Composers of the seventeenth and eighteenth centuries wrote music specifically designed to highlight the complexity of the MDV. The nineteenth century witnessed a change of style toward a generalized realism. The operas of Rossini and Bellini notwithstanding, a more declamatory vocalism began to be valued. Thus, the MDV began to disappear as a compositional device but continued to be prized in the studio.

Francesco and Giovanni Battista Lamperti

Two other historically important teachers of the nineteenth and early twentieth century, Francesco Lamperti (1811 or 1813-1892) and his son Giovanni Battista Lamperti (1839-1910), had their own unique approaches to the MDV. Their technique was greatly influenced by the 1874 writings of the French physiologist Louis Mandl whose *Hygiène de la Voix pour Parlée ou Chantée* described the "*lutte vocale"* or vocal struggle between the inspiratory and the expiratory forces while attacking, sustaining, and releasing the tone.[16] To control dynamics requires the same effort internally, the glottal pressure must remain constant, and the abdominal flexion must not release in the singing of *piano* but must remain steady in order to color and animate the voice.[17] Therefore, we arrive at a contest between the main muscle of inspiration, the diaphragm, and the abdominal and costal musculatures of expiration. The Lampertis seem to be echoing the sentiments of Garaudè rather than Garcia: "*Piano* should in all respect, with the exception of intensity, resemble the *forte;* it should possess the same depth, character, and feeling; it should be supported by an equal quantity of breath and should have the same quality of tone."[18] "Singing loudly is releasing; singing softly is restraining the pent-up energy in compressed air filling the lungs coordinately gauged in doing so."[19] And "Finally the voice controls the breath--not the reverse."[20] There is no suggestion of changing registers or timbres and no room for loose glottal closure in the execution of the Garaudè/Lamperti MDV.

Both the Garcia school and the Lamperti school boast a roster that includes the greatest practitioners of *bel canto.* Garcia taught Jenny Lind, Mathilde Marchesi, and Julius Stockhausen among others. Francesco Lamperti's students included Italo Campanini, Emma Alboni, and Teresa Stolz. G.B. Lamperti taught David Bispham,

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[16]Louis Mandl, *Hygiène de la voix* (London: J.B. Baillière et fils, 1876), 11-13.
[17] Francesco Lamperti, *The Art of Singing According to Ancient Tradition and Personal Experience,* trans. W. Jekyll (London: Ricordi, 1884), 52.
[18] Francesco Lamperti, *The Art of Singing,* trans. J.C. Griffith (New York: G. Schirmer, 1916), 19.
[19] William Earl Brown, *Vocal Wisdom: Maxims of Giovanni Batiista Lamperti* (New York: Arno Press, 1957), 61.
[20] Ibid., 134.

Marcella Sembrich, Ernestine Schumann-Heink, and Roberto Stagno. Considering the diversity of styles across a range of vocal music, it may seem the Garcia school represented the "old style" of Mozart, Gluck and the great triumvirate of Italian *bel canto* composers Rossini, Donizetti, and Bellini, whereas the Lampertis were wedded to the emergent style of *verismo* and the unique demands brought about by the music dramas of Richard Wagner and the Verdian melodrama.

Legacy of the Nineteeth Century

The nineteenth century played host to a vast shift in singing styles related to the ever-changing demands of new repertory and new tastes. Garcia was rooted in the golden age of the past. His father, after all, one of the most celebrated artists of his time. The vocal attributes most prized were flexibility and nuance, necessary elements to adequately perform the repertoire of the immediate previous generation. However, new operas were being written to highlight a large orchestral sound and an improved sense of theatrical values with importance laid upon drama, scenery, and stagecraft. The Lampertis equipped their students with the necessary tools to manage the new vocal demands. They also were linked with a theatrical agency in Milan, so they were a direct pipeline to the managements at the Italian opera houses. The voice was no longer the sole attraction, and the singer was made to fit into a machine made of equal parts. Simple sonic competition with the larger more powerful orchestra and delivery of more text centered musical drama forced a shift of values related to matters of voice. The new technique focused on vocal projection and declamation, and even seemed to accelerate the arduous training process. This is apparent in the two differing approaches to the

MDV. One begins with a light glottal closure, which implies, or forces depending on one's point of view, the falsetto register in a gesture of flexibility and nuance. The other begins with complete glottal closure and does not acknowledge a change of register, engaging from beginning to end in the vocal struggle between inspiratory and expiratory effort. These two great pedagogues were never so inflexible as their printed words implied, and there are ample practical opportunities for blending the two approaches. Garcia himself wrote, "It is necessary to pinch the glottis in proportion to the amount of pressure one gives the air."[21] This is closely related to the *lutte vocale* and proof that, regarding the MDV and in turn *bel canto* technique in general, a multi-level balancing of forces is necessary to maintain the poise and placement of the voice.

Modern Age

In the twentieth century and beyond, the *messa di voce* continues to function as the ultimate test of coordination for the *bel canto* trained singer. From the Italian verb "*mettere"* (to put, to place) the nominative term, *messa,* offers a wide range of interpretation. The placing of the voice is a very important concept in the *bel canto* tradition and has direct connotations for practitioners of the vocal arts. However, each singer's instrument is unique, and sensations of placement can differ significantly from individual to individual. Placement can be imagined as a sympathetic resonance cavity, a postural positioning or poise, a foundational sense of support, or any number of other misleading visual images. It is not possible to place a sound. William Vennard interprets *"messa"* as "mass" in his influential book *Singing: The Mechanism and the Technic,* the

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[21] Garcia, 27.

first anatomic and scientific text written on the voice in America.[22] The definition can easily be accepted, as the body of the vocal folds experience changes to their mass during a MDV. Cornelius Reid provides several alternate versions of the MDV and traces its origin to the *"note filate"* or "spun note:"[23] "The *messa di voce* lends itself better than others as vehicles affecting a solution to the problem at hand. In learning to swell and diminish, it is evident that a single tone best serves this purpose."[24] The difficulty and therefore the dilemma of when to introduce the exercise is presented by Richard Miller: "Attempts to achieve the highly controlled *messa di voce* must wait for general technical stability. Only the singer who has fundamentals of vocal technique well in hand should attempt these vocalises."[25]

Voice Science and *Messa di Voce*

Ever since that day in 1854 when Manuel Garcia II first viewed his vocal folds in the act of singing by employing the recently developed laryngoscope, the search for quantifiable data regarding the action of the vocal apparatus has been consistent and ongoing, and the vocal pedagogical world is now dominated by the discipline of vocal science. This study builds on new research and new technological developments in voice science to address technical issues of MDV production; the study clarifies and further defines the physiological and acoustical functions involved in producing a singing tone.

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[22] William Vennard, *Singing; The Mechanism and the Technic* (New York: Carl Fischer, 1957), 213.
[23] Cornelius Reid, *Bel Canto Principles and Practices* (New York: Coleman-Ross, 1950), 100.
[24] Cornelius Reid and George Shirley, *The Free Voice: A Guide to Natural Singing* (New York: Oxford, 2018), 129.
[25] Richard Miller, *The Structure of Singing: System and Art in Vocal Technique* (Boston: Schirmer, 2013), 175.

In the voice laboratory the MDV is a most useful tool for assessment. Its highly specific demands are intricately connected and promote energy and flexibility across the entire compass of the voice. Since proper execution of the MDV encompasses so many facets of vocalism, it provides an ideal tool for technique development.

This study uses subjects trained in the art of *bel canto*. Previous voice science research has made use of the MDV to measure such elements as subglottal pressure, transglottal airflow rates, closed and open quotients of the vocal folds, laryngeal depth, and formant frequencies.[26] The gradual shift of forces involved in the dynamic maneuver are observable at both the physical and aural levels. Unfortunately, rarely have subjects with significant professional experience been called upon to participate. The value of experience gained in managing one's voice through a professional career is significant, especially with an exercise as intricately balanced as the MDV. Only trained *bel canto* singers possess the knowledge and experience of their own voices to undertake the intricate acoustical and physiological adjustments necessary to perform the extremely difficult vocal maneuver. They also possess greater control of acoustical balance. Research has shown that professional singers exhibit far greater spectral energy in the area of the singer's formant cluster than do nonprofessionals.[27] This project will also document the subjects' reactions and sensations. Due to the nature of the voice, much of

[26] See especially Sally Collyer, et.al., " Sound Pressure Level and Spectral Balance Linearity and Symmetry in the *MDV* of Female Classical Singers," *Journal of the Acoustical Society of America* 121 (2007): 1728-1736; Donald Miller and Harm K. Schutte, "Measurement of Characteristic Leap Interval Between Chest and Falsetto Registers," *Journal of Voice* 16, no. 1 (2002): 8-19; Peta Sjölander and Johann Sundberg, "Spectrum Effects of Subglottal Pressure Variation in Professional Baritone Singers," *Journal of the Acoustical Society of America* 115 (2004): 1270-1273; Ingo Titze, et.al, "*Messa di voce*: An Investigation of the Symmetry of Crescendo and Decrescendo in a Singing Exercise," *Journal of the Acoustical Society of America* 105 (1999): 2933-2940.

[27] Sam Fergusun, D.T. Kenny, and D. Cabrera, "Effects of Training on Time-varying Spectral Energy and Sound Pressure Level in Nine Male Classical Singers," *Journal of Voice* 24, no.1 (2010): 42.

traditional and historical vocal pedagogy has relied primarily upon the stimulation and recognition of particular sensations of resonance, structural support, airflow, and pressure. The project will also examine the subjects' sensations of breath flow, resonance, stability, laryngeal depth and control of onset and release of the tone, and how the data corresponds with the subjects' reactions.

Videokymography and a Clear View of Vocal Function

Technology has provided several avenues to obtain real-time visual feedback of sound production. The analysis of data collected from Videokymography consists of single-line scanning of the vocal folds with a modified camera attached to the rigid arm of a 70 or 90 degree endoscope. The camera can record in a high-speed mode of up to 8000 images/second which can easily cover a complete range of vocal pitches, extending into the soprano high voice. Observation is possible of left and right vocal fold symmetries/asymmetries, closed and open quotients of the glottis, views of the upper and the lower margins of the vocal fold, and most intriguingly, the propagation of mucosal waves. The images can be directly displayed in real time on a standard video monitor without waiting for post-processing. The sequential kymogram of the vibrating vocal folds is retrievable from a kymographic image sequence. The data collected from the kymogram sequence is then available for quantitative analysis. Recent research led by Philippe Dejonckere has made use of this technology to record a single male subject vocalizing a *messa di voce*.[28] The resultant kymographs display three significant points

[28] Philippe Dejonckere, Jean Lebacq, Leonardo Bocchi, Silvia Orlandi and Claudia Manfredi, "Automated Tracking of Quantitative Parameters from Single Line Scanning of Vocal Folds: A Case Study of the 'Messa di Voce' Exercise," *Logopedics Phoniatrics Vocology* 40, no. 1 (April 2015): 44-54.

during the exercise: (a) early vibration at a soft dynamic; (b) approximately halfway to maximum threshold of sound pressure level; (c) maximum sound pressure level (halfway through the cycle). At soft phonation the edges of the vocal folds barely make contact for a very short closed phase (**Figure 2a**). Contact becomes fuller and the closed phase longer as amplitude increases (**Figure 2b**). Finally, the full crescendo reaches maximum contact, closure, and loudness (**Figure 2c**).

Figure 2a: Videokymogram of beginning of MDV.[29]

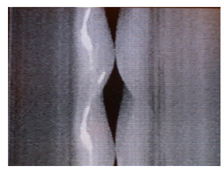


Figure 2b: Videokymogram of middle of crescendo.[30]

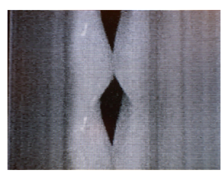
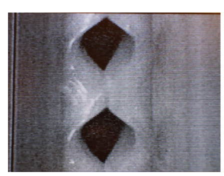


Figure 2c: Videokymogram of full crescendo.[31]



[29] Ibid., 49.
[30] Ibid., 49.
[31] Ibid., 49.

This sample is remarkably symmetrical, showing relatively balanced right vocal fold/left vocal fold symmetry, contact, and fold depth, all displaying a healthy vocal function. A spectrographic analysis of the voice picked up by a microphone signal is necessary to determine the unique voice print and extent of energy produced throughout the frequency spectrum. This can easily be paired with kymographic analysis. Then can be seen the relationship between auditory response and source function. A significant drawback in the use of videokymography is the high cost and relative inaccessibility. Yet armed with the knowledge gleaned from previous and continuing laboratory research such as that spearheaded by Dejonckere, employing highly advanced technologies found primarily in research hospitals, a voice teacher with knowledge of physiological function will find frequency analysis a valuable graphic representation of vocal-acoustic function. However, since the availability and expense of videokymography is so restrictive, a more readily available, less expensive technology can be employed. Spectrographic analysis of fundamental pitch, resonated harmonics, amplitude, vibrato rate and excursion, vowel integrity, sound pressure level, and dynamic variation is now available on applications for hand-held devices such as smart phones and tablets.

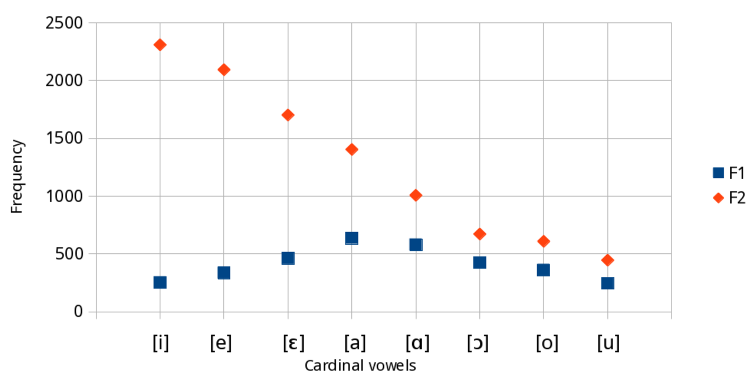
Auditory Frequency and the Singing Voice

The fundamental frequency of a pitch has a series of harmonics pulsating at the rate of the fundamental. The harmonics function as a logarithmic ratio of the fundamental frequency and descend in interval as they increase in distance from the fundamental. Therefore, labelling the first harmonic H1, it is heard as the fundamental pitch. H2 is an octave above. H3 a perfect fifth above H2, H4 a perfect fourth above H3, and so on. The fundamental frequency of a sung pitch is produced by the vibrating vocal folds and filtered through the vocal tract which strengthens or weakens the series of frequencies fed to it by the voice source. The perception of pitch and rate of vibration is controlled primarily by the muscular relationship between the thyroarytenoid muscles and the cricothyroid muscles. The thyroarytenoid muscles make up the body of the vocal fold and work to shorten and thicken for lower frequencies. The cricothyroid muscles are involved in stretching and thinning the vocal folds for higher frequencies. In short, thyroarytenoid-dominant phonation is noticeably chest dominant while cricothyroid-dominant phonation is head dominant. The "chestier" tone has greater vertical fold contact and produces complex high harmonics. Its timbre is brassy and open. The "headier" vibration is first harmonic dominant with little high frequency intensity. The thinner fold contact tends to divide the vibratory pattern into an equalized sinusoidal waveform. The timbre is flute-like, flowing. The intensity of a sound can be predicted by the frequency pattern of the source tone. A tone richer in high frequencies will be perceived as louder. A tone with little high frequency activity will be perceptually softer. The *bel canto* trained singer seeks a source tone that freely sounds the higher frequency band and then adjusts their vocal tract to enhance, cluster, or dampen the resultant harmonics as appropriate.

Vowel Formants

The vocal tract is partially closed at the glottis, and open at the lips. This is the design of a quarter-wave resonator because the sound wave resonates at four times the length of the vocal tract. The standing wavelengths of the higher frequencies are oddnumbered multiples of 1/4. The malleable nature of the vocal tract enables it to boost source harmonics that are near its peak resonance frequencies. These tunable resonances within the vocal tract are called formants. Their frequency and location are dependent upon the length and shape of the laryngeal tube. The longer the tube, the lower the frequencies, and therefore the greater number of audible formants. The shorter the tube, the higher the frequencies resulting in fewer available formants. The first two formants, labelled F1 and F2, are the most affected by changes in the vocal tract and are the most tunable. The average frequency location of the cardinal vowels for speech is displayed in **Figure 3**. They are responsible for clarity of vowel color and are therefore known as vowel formants.

Figure 3: Frequency locations for vowel formants F1 and F2.[32]



Formant Tuning

The first formant is responsible for the depth and warmth of sound. It is the lowest

[32] Olle Linge, "Playing with PRAAT, Part 1: Cardinal Vowels and Vowel Space," *Languages, Literature, and the Pursuit of Dreams,* http://www.snigel.nu/wp-content/uploads/2014/04/cardinal-vowel-formant-graph.png (accessed 13 November 2019).

resonance of the vowel. It can lie between C4 and C6. For proper *chiaroscuro* it is necessary to have a harmonic derived from the source tone that is near an F1 frequency peak. Otherwise the sound will be thin and lacking in color: "It is also useful to know that the lower the frequency of F1 relative to the vowel being sung, the more open the throat is."[33] And the more open the throat is, the more available resonance there is. To lower the first formant, a singer will sing a more close vowel, toward a vowel with a lower first formant. To raise the first formant, a singer will sing a more open vowel, toward a vowel with a higher first formant. According to Kenneth Bozeman, a leader in the world of vocal acoustics, "Whenever a source harmonic passes through the first formant, there is an audible effect (some degree of opening or closing of the timbre with an accompanying, simultaneous passive vowel modification), which is perceivable as an acoustic registration phenomenon."[34] This seems to equate well with Garcia's notion of the MDV as a dynamic event involving flexibility of support and phonation passing through a registration event. An acoustic registration event is characterized by an audible timbral shift that occurs with no change to the laryngeal mechanism. As each harmonic intersects the first formant this shift occurs. The most prominent one in male voices occurs as H2 approaches the peak frequency of the first formant, which occurs in the upper male *passaggio*. This is historically thought of as a laryngeal shift, involving a rebalance of phonatory muscular function and corresponding sensations of turning the voice. But from the view of vocal acoustics, this imbalance is merely an acoustic shift in frequency vibration. "If turning over were the result of laryngeal registration rather than first formant locations, one would expect a voice to turn over at the same pitch for all

[33] Kenneth Bozeman, *Practical Vocal Acoustics* (Toronto: University of Toronto Press, 1999), 13.
[34] Ibid., 14.

vowels. It does not. Maintaining that view is no longer a viable pedagogic position."[35] As the source harmonics change with the rising pitch, they react to the stable formant resonances of the vocal tract. Subtle formant/harmonic tunings are necessary to maintain consistent color, weight, and *chiaroscuro* balance appropriate to *Fach.*

The second formant is responsible for the clarity of vowel sound. It also takes part in certain acoustic resonance strategies for the male high voice and female middle voice. In the male upper *passaggio,* as H2 nears and passes the peak of F1, the distance between H1 and H2 grows to over an octave. The loss of power can be so dramatic that many males couple the second formant with a higher harmonic within its bandwidth. For front vowels with a high frequency second formant this could be H4 or higher; for back vowels with a low second formant it is most likely to be H3.[36] The frequency boost produces a voice that is brighter. Females can practice the same strategy at approximately the same fundamental frequency range, E4 to A4, to produce a brilliant sound in the lower middle range of their voices.

Singer's Formant Cluster

In a balanced *chiaroscuro* tone, formants three, four, and five band together to produce the singer's formant cluster. It is the ringing quality in an operatic voice that allows it to fill a large space with sound and be heard over a full orchestra: "Those who are instructed in its use can detect in a moment, from the mere sound of the voice,

[35] Ibid., 26.
[36] Donald Gray Miller, *Resonance in Singing: Voice Building Through Acoustic Feedback* (Princeton, NJ: Inside View Press, 2008), 23.

whether it is being employed or not, so that the term 'singing' has a special significance for those who have been taught to use it."[37]

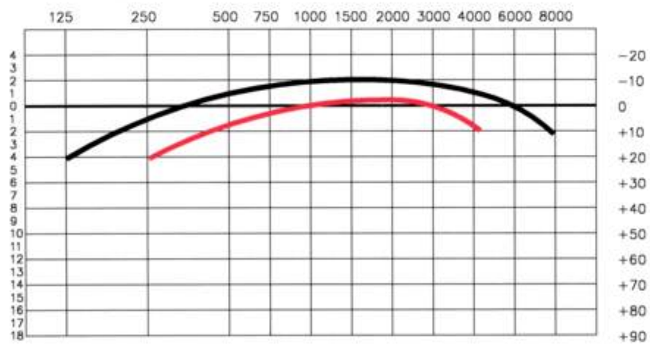
Auditory Frequency and the Ear

The frequency zone of the singer's formant cluster (circa 3000Hz) resides in the area where the human ear is most sensitive to amplitude. Like the vocal tract, the human ear canal is also a quarter-wave resonator, and sound heard in the 2000Hz-3000Hz range receives a boost on its way to the eardrum. Although the range of human hearing can extend up to 20,000Hz, all vocal sound above 4000Hz drops away quickly in intensity. However, around 7000Hz-10,000Hz some voices present another spike in resonance, though more study is needed to determine what effect these "shadow formants" have on the overall sound or what their significance might be to phonation and balance of acoustic pressures. Obviously, the voice was made for the ear and the ear made for the voice. Their parallel sympathetic sensitivities make that readily apparent. The shape of the listening curve of a musical ear is similar to the complex vibratory frequency pattern of the dense *chiaroscuro* tone of a *bel canto* trained singer (**Figure 4**). Therefore, an element of *bel canto* training is devoted to the development of the ear. The singer must be able to imagine the sound they are going to produce before phonation. According to the discipline of psycho-acoustics, the properly resonated voice can have dramatic effects on the mind and body. It can bring the body into proper alignment, stimulate brain activity, and have a profound impact on one's emotional state. Acutely filtered sound is used therapeutically to promote learning, instill a calming effect, manage mental challenges

[37] Franklyn Kelsey, "Voice Training." in *Grove's Dictionary of Music and Musicians,* ed. Eric Blom, vol. 9, 5th ed. (London: Macmillan, 1954), 54.

such as Attention Deficit Hyperactivity Disorder and Asperger's Syndrome, and help overcome language and speech difficulties. Alfred Tomatis, one of the pioneers in this field, was a French ear. nose, and throat doctor who specialized in rehabilitating opera singers. He discovered that the vocal difficulties of his patients had as their source a divergent listening curve. Once the ear had been retrained to hear a proper balance of

Figure 4: The listening curve of a musical ear: red = bone conduction; black = air conduction.[38]



resonance, highlighted by the unique singer's formant cluster ring, the singer regained voice use. Training internal hearing through bone conduction and the primacy of the right ear, which is more sensitive to high frequencies than the left, the *bel canto* singer is led toward vocal assurance and freedom:[39] "*The larynx does not emit what the ear does not control.*"[40]

The human voice put to the highly specific task of *bel canto* singing will forever wear an aura of mystery. However, the ever-increasing store of scientific knowledge and

[38] Alfred A. Tomatis, "The Listening Curve of the Musical Ear," The Listening Centre, December 17, 2013, https://www.tuneyourears.com/html/Listening_Therapy/listeningcurve.php.
[39] Alfred A. Tomatis, *The Ear and the Voice* (Lanham, MD: Scarecrow Press, 2005), 92.
[40] Ibid., 21-22.

the employment of new technologies to quantifiably assess elite singing maneuvers will aid pedagogues and students of the vocal arts in their progress toward unlocking the *bel canto* potential within themselves. The key to discovery is in the analysis of an elite *messa di voce*. With the aid of modern technology and the benefit of a storehouse of knowledge, under-researched elements such as mucosal wave propagation and vertical depth, which anecdotally play an important role in subtle fine-tuning for the elite singer, may now receive closer examination. The ability to view and analyze the frequency output of the voice in real time with a handheld device holds remarkable value for the teacher, student, and professional singer. leading to the advancement of the art of *bel canto*.

Study: A Comparison of Formant Frequencies in Two Methods of *Messa di Voce*

A study of MDV was conducted to test the premise that the Garcia and Lamperti approaches may result in an acoustic alteration in the voice and/or a change in the sensory feedback perceived by the singer. Directly stated, it is common experience among singers and pedagogues that the Garcia method induces flexibility and roundness and the Lamperti method provides stability and brilliance. Although the vocal arts cannot be reduced to numerical analysis, differences in spectral intensity are evidenced in spectrographic displays. For this study, recorded samples of the performance of MDV by four singers were taken in a private studio space, and spectrograms and graphs were generated. The four singers volunteered for the study. Three have been performing professionally for at least twenty years. The other singer is a young *bel canto* trained singer at the beginning of her career. The samples were recorded and measured at a rate of 96kHz by Audio Analyzer, an iPhone application developed by Pavel Kryzwdzinski at iAudioApps. The utility of the application is enhanced by its portability and ease of use. Picture-in-picture allows a simultaneous view of the spectrogram and power spectrum in real time. Input level can be set within the range of -144dB and -10dB. Input was set at -92dB for the females and -72dB for the males. A 2048 bit Hanning window size was chosen. An informal interview preceded by a discussion and clear definition of the MDV was conducted before samples were taken. After the singing of the exercises, an informal interview was conducted. Questions were asked about sensory feedback, ease or difficulty of execution, and practical uses.

The discussion that follows will examine each method's recorded spectrogram, comparing and contrasting relevant data such as onset and offset, spectral slope, and rate and extent of vibrato. Examining the power spectra at different dynamic levels illuminated the harmonic-formant relationship within the vocal tract and the presence and consistency of the singer's formant cluster. The singers were asked to sing a smooth linear crescendo-decrescendo on a single pitch for a duration lasting approximately ten seconds on the phoneme [a]. Three pitches were given: one in chest register, one in middle register, and one in head register. Each pitch was sung in two different ways: one according to Manuel Garcia II's method of instruction, an onset in falsetto with the larynx low and the tone dark (hereafter known as the Garcia method), and the other by the *lutte vocale*, or management of glottal pressure espoused by the Lampertis (hereafter referred to as the Lamperti method). Each singers' spectrograms were examined. A discussion of results and trends follows.

Subject 1: Soprano

The pitches for Subject 1, a soprano begin with E4 (330Hz). This pitch lies in the *primo passaggio* from chest register to middle register for the soprano voice. The first formant for the vowel [a] is produced at 850Hz; there are two harmonics, 330Hz and 659Hz available for tuning below it. According to the Lamperti method, the singer is not to change register, which would mean a consistent harmonic balance throughout. **Figure 5** shows the MDV on E4 as produced by the Lamperti method**.** The fundamental and H2 are in balance, each mirroring the other's vibratory pattern in the decrescendo. **Figure 6** displays the spectrogram for the Garcia method migrating across registration events.
For the soprano to maintain a harmonic equilibrium, an acoustic and physiological adjustment must be made in order to produce a balanced and dynamic tone. Balance between the thyroarytenoid and cricothyroid muscles produces a mixed tone. This avoids a binary laryngeal adjustment during the crescendo and decrescendo in the Lamperti approach. There is a dominant first formant color at the onset and a clear outline of the vowel formants. The Garcia method produces a balanced onset with a clear delineation of partials across the spectrum and an H2/F1 pairing. Notice the lack of definition in the vowel formant region. During the crescendo but still at the *piano* dynamic, the Lamperti method remains consistent in its separation of frequency peaks, keeping H2 and F1 apart and at equal intensity. In contrast, the Garcia method draws H2 and F1 together around 700Hz. In the Lamperti, a strong intensity at the fundamental keeps the second harmonic separate from the first formant, creating a harmonic spread that balances the partials of the source tone with the vowel formants. Only at *mezzo forte* does the intensity of the lowered first formant surpass the other resonance peaks. Garcia's *mezzo forte* relies on

the H2/F1 coupling and an increase in the singer's formant cluster. At *forte* the Lamperti acoustic strategy remains consistent. The adjustment is not audibly apparent on the decrescendo, displaying high level control of vocal emission. The decrescendos mirror the crescendos: Lamperti's rebalancing spread led by the fundamental, and Garcia lowering the first vowel formant to pair with H2.

Figure 5: Subject 1, E4 (330Hz) full spectrogram, Lamperti method.

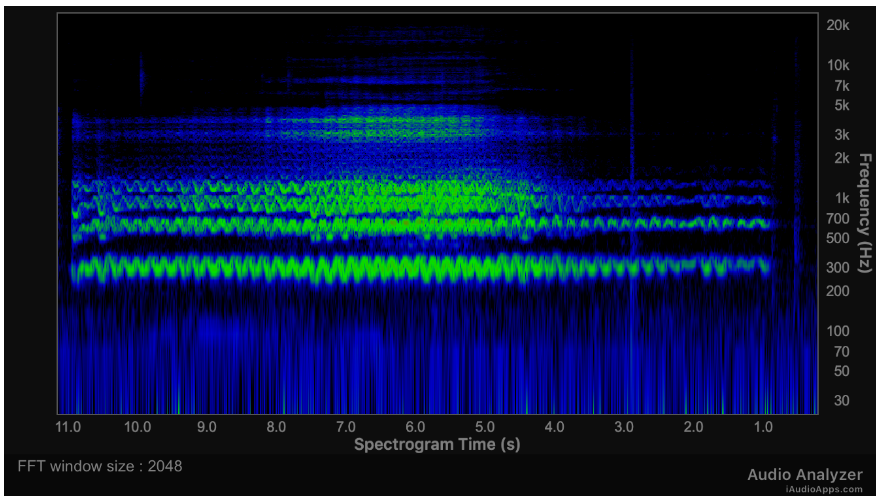
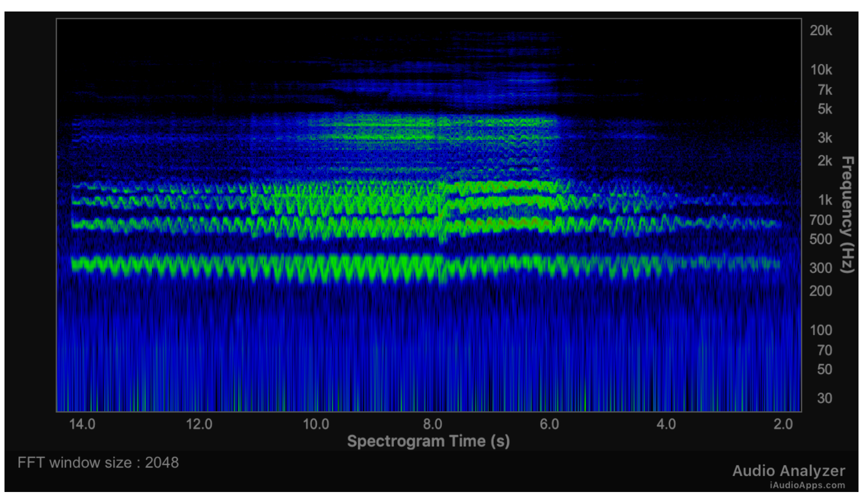


Figure 6: Subject 1, E4 (330Hz) full spectrogram, Garcia method.



The behavior of the vocal tract in this example is true for almost all samples: a clear vowel formant structure coupled with strong relative intensity in the singer's formant cluster for Lamperti's method and a consistent downward slope at onset for the Garcia method. The dynamic change is made by a stable vocal tract and gradual increase in breath energy and glottal resistance in the Lamperti method. For the Garcia method, a modulating vocal tract, amplifying and attenuating different partials along the way through a constant reshaping, controls the MDV.

The next pitch is B4 (494Hz), which lies near another acoustic shift. The second harmonic of B4 (988Hz) nears the first formant frequency of [a] (850Hz), and the soprano displays a tuning of the first formant to the second harmonic in both approaches to the MDV. A cleaner onset led by the first formant resonance and greater amplitude at *forte* with Lamperti and a more intense singer's formant cluster with Garcia are the only measurable differences (**Figure 7** and **Figure 8**).

The onsets reveal a key difference in the manner in which the tone is begun. The Lamperti method begins with a sharp onset led by the raised first vowel formant/lowered second harmonic, circa 950Hz. Garcia begins with a strong fundamental pitch, circa 494Hz, which sets the posture of the vocal mechanism in position to create a deep, somber tone as per instruction. Visible is a small peak near the first formant of the vowel [u] (circa 300Hz) revealing the vertical depth maintained at onset, Garcia's dark timbre. The journey to *forte* involves a continued first formant second harmonic dominance in the Lamperti method. The Garcia method as well relies on this coupling. The difference being in the location of the resonance peak. The Lamperti approach results in a lowered peak around 810Hz. The Garcia method raises the peak over 1000Hz. The wide bandwidth of the frequency peaks enables the coverage of a large array of vowel color. The Lamperti method emphasizes the lower end of the peak spectrum while the Garcia

Figure 7: Subject 1, B4 (494Hz) full spectrogram, Lamperti method

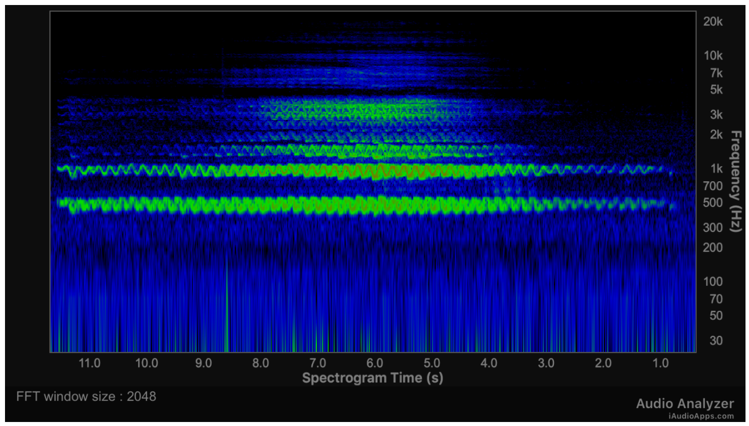
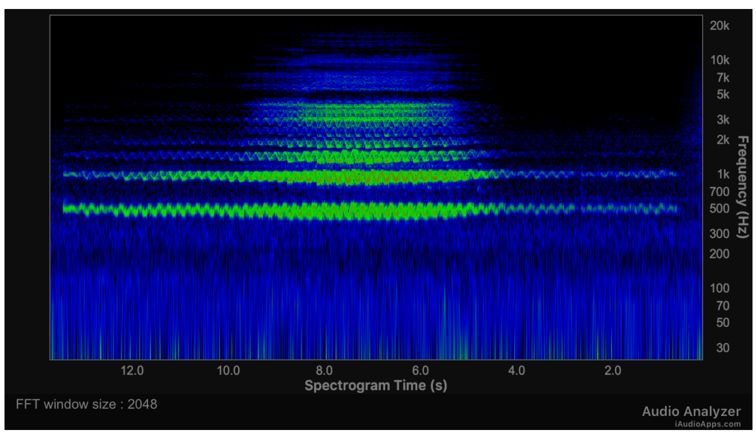


Figure 8: Subject 1, B4 (494Hz) full spectrogram, Garcia method



method rings on the upper end of the spread. The decrescendos display the same pattern. To avoid the register shift, the Lamperti method remains led by the first formant/second harmonic coupling. The Garcia method allows the voice to adjust registration and returns the dominant harmonic to the fundamental. Both methods employ a shift in timbre, mixing the [a] vowel with elements of [u] (F1=370Hz, F2=950Hz) and [o] (F1=590Hz, F2=920Hz) allows for a dynamic acoustical tuning to occur.

Subject 2: Baritone

The heavy chest register of Subject 2, a baritone, nears its upper limit at F3 (175Hz) because the third harmonic of the pitch (523Hz) is approaching the first formant of the vocal tract (730Hz). A few more half-steps will initiate an acoustic shift. The spectrograms are similar, including the asymmetrical spectral slope: a long crescendo and a shorter decrescendo (**Figure 9** and **Figure 10**). The third harmonic directs most of the acoustic activity at this pitch as evidenced by the resultant spectrograms and power spectra. Both onsets are clean, with the Garcia attack beginning just below the pitch. The Lamperti onset is characterized by a brisk, sharp attack. The difference lies in the acoustic strategy. As the crescendo occurs the Garcia method remains led by the third harmonic balancing the first formant. The Lamperti method results in a shift of acoustic intensity to the second formant and a brighter, clearer sound. The Garcia method results in a consistent balance between H3 and F1 and a warmer, deeper sound. As the crescendo occurs, F1 receives a boost from the energy of H4. The Lamperti method crescendos to greater amplitude and is led by a boosted second formant in the region of the eighth harmonic (1175Hz).

The next pitch is C4 (262Hz) which lies near the *secondo passaggio* for the baritone. This is the area of the voice that is most effectively mixed with chest and head registers. The pitch C5 (523Hz) which was encountered as the third harmonic of F3 is now the second harmonic of C4 and once again encroaching on the frequency range of F1

(730Hz) (**Figure 11** and **Figure 12**). The even wavelength pattern and even vibrato in **Figure 11** is contrasted with the irregularities in the crescendo in **Figure 12**. The Lamperti method is led consistently throughout by the second harmonic (523Hz), even at the onset. The tone remains harmonically balanced, with little change in the relationship

Figure 9: Subject 2, F3 (174Hz) full spectrogram, Garcia method

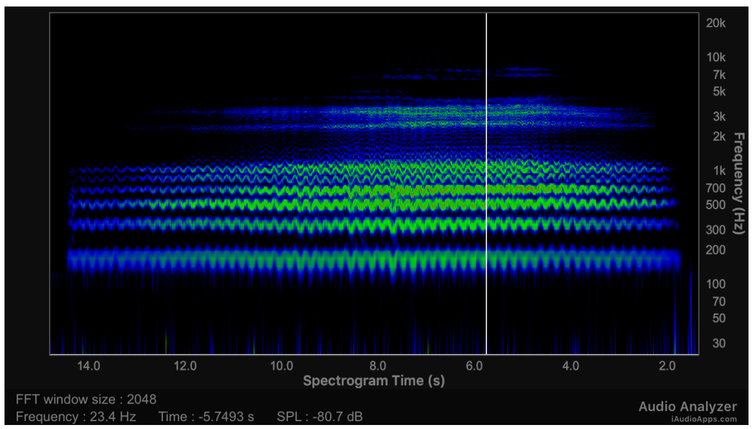
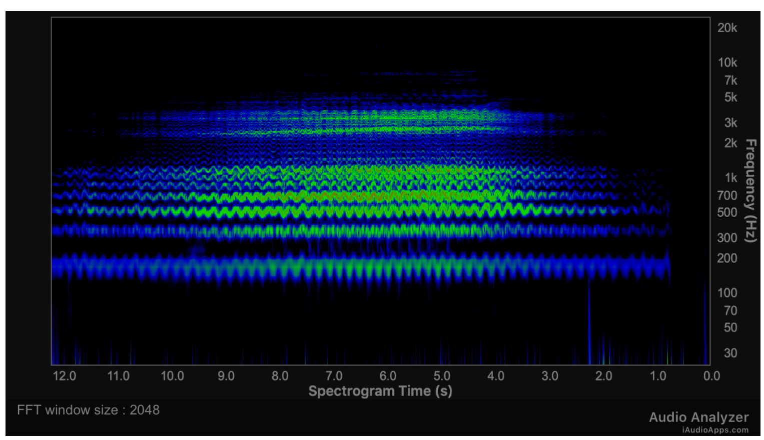


Figure 10: Subject 2, F3 (174Hz) full spectrogram, Lamperti method



among the frequencies throughout as per the method of the *lutte vocale*. The third harmonic remains coupled with the first formant (730Hz), and the fourth harmonic (1047Hz) with the second formant (1090Hz). The dynamic variation is simply managed by control of breath pressure and glottal resistance. The Garcia example begins with a strong fundamental and first harmonic leading the way. The approach balances the intensity of the second harmonic with the fundamental and the vowel formants, which remain strong throughout relative to the first and second harmonics. There is acoustic boosting evident at *mezzo forte* as H2 and H3 pair more completely with F1 and F2 respectively. At *forte*, the second formant is raised along with the singer's formant

Figure 11: Subject 2, C4 (262Hz) full spectrogram, Garcia method

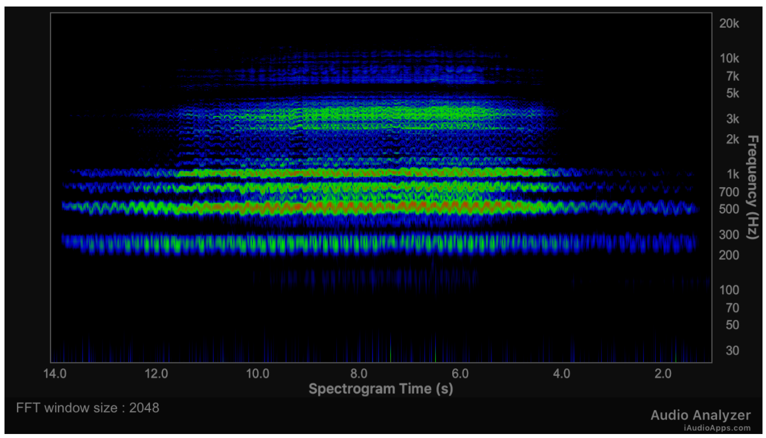
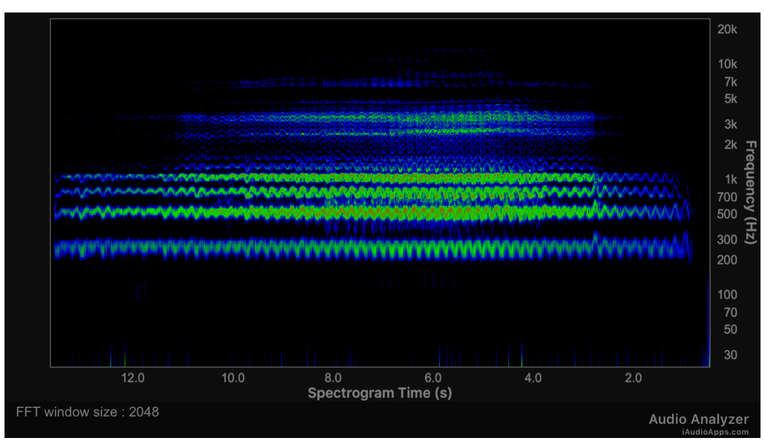


Figure 12: Subject 2, C4 (262Hz) full spectrogram, Lamperti method



cluster, which rises above the level of the fundamental. There is greater distance between the peaks at the fundamental frequency and the upper partials. There are binary shifts from cricothyroid-dominant phonation to thyroarytenoid-dominant production and back again across the dynamic range. While this shift is a necessary function in the Garcia method, *bel canto* training masks its audibility.

The pitch F4 (349Hz) lies at the junction of the high end of the *secondo passaggio* and the head voice. Again, it is a meeting point of harmonics and formants in the baritone voice. This time the third harmonic (1047Hz) reacts with the second formant of the vocal tract (1090Hz). The spectral intensity has greater linearity and range of dynamic variation in the Garcia method than in the Lamperti method (**Figure 13** and **Figure 14**).

The onsets reveal key differences in the technical strategy. The Garcia onset is characterized by a strong fundamental, the result of a generous mixing of [u] with [a], taking advantage of the first vowel formant proximity to the fundamental. This enables a gentle attack to the tone. The Lamperti method's onset is clean and sharp, with a full, balanced tone from the beginning. The Garcia crescendo to *mezzo forte* shows a strong peak at the third harmonic/second formant blend, resulting in a full and heady tone. A ringing, balanced [a] vowel is produced at *mezzo forte* in the Lamperti approach. In the Garcia method as the baritone crescendos to *forte,* more medial compression/glottal resistance and an increase in breath pressure lowers the second formant, bringing it in balance with the first formant, and raises the amplitude of the fundamental frequency to produce a brighter more open sound. The Lamperti decrescendo is a unified lessening of intensity across the spectrum. The Garcia decrescendo is managed by a drop in all frequency intensities above the fundamental.

Figure 13: Subject 2, F4 (349Hz) full spectrogram, Garcia method.

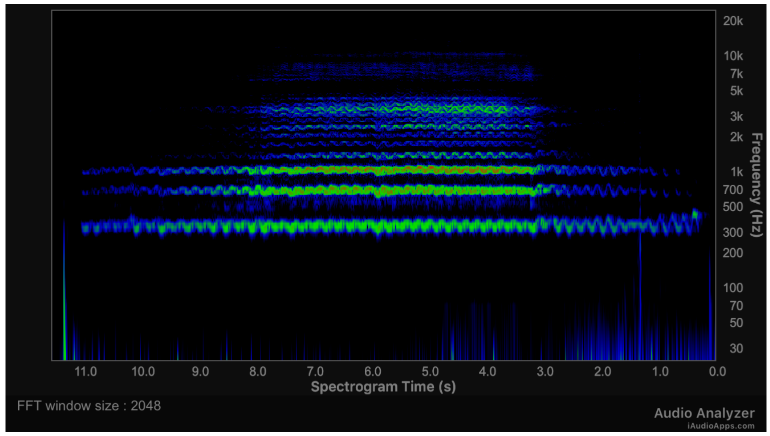
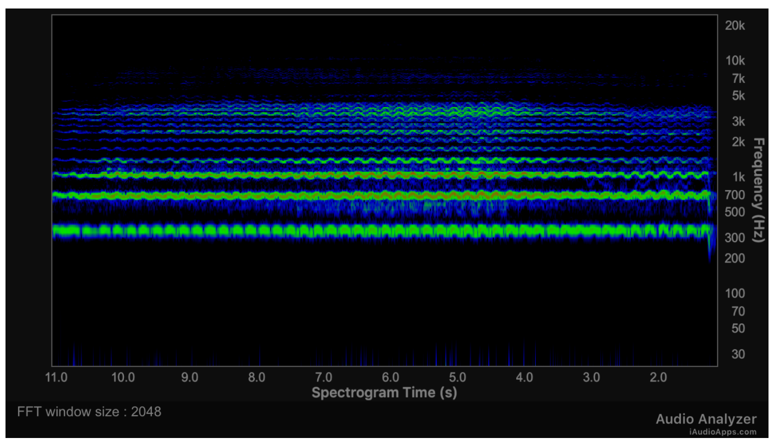


Figure 14: Subject #2, F4 (349Hz) full spectrogram, Lamperti method.



Subject 3: Soprano

The first pitch in Subject 3's series is Bb3 (233 Hz), which sits low in the vocal range and squarely in chest register. A comparison of spectrograms reveals a narrow vibratory cycle in both methods. The spectral balance is variable with more spread across the Lamperti, but the fewer resonant frequencies in the Garcia method are relatively intense. Oddly, the Garcia example lacks significant energy at the fundamental (**Figures 15** and **16**).

The onsets are both clean, with the vowel in Lamperti clearly articulated, evidenced by balanced harmonics and vowel formants. The onset in the Garcia example is resonant with a balanced harmonic profile with four main resonance peaks, but little vowel definition. The peak at around 300Hz seems to be an indicator of a [i] shaped vocal tract. The onset also is a bit below the fundamental frequency. There is evidence of the singer's formant cluster. Interestingly, the Garcia approach never produces strong resonance at the

fundamental frequency. During the crescendo to *forte* the resonance peak passes from the H3/F1 pairing to H5/F2 as the tone is constricted at the front of the vocal tract. Along with the increased energy in the range of the singer's formant cluster, the bulk of the perceived increase in amplitude is carried by these acoustic adjustments.

As in the Garcia method, the Lamperti crescendo to *forte* is carried by the H5/F2 pairing and an increase in intensity and compression of the singer's formant cluster, but with a much stronger fundamental frequency. There is also an interesting reaction in the vocal tract at the level of the second harmonic. A strong second harmonic at *mezzo forte* is attenuated as the focus of the sound energy is transferred to higher and higher frequencies, and the sound pressure level of the area above 1000Hz rises above the fundamental taken at this session. The well balanced Lamperti decrescendo is affected mostly by a drop of intensity in the singer's formant cluster which allows the substance of the tone to remain strong as the ringing quality is reduced considerably. This is in contrast to the Garcia approach where the fundamental frequency is overwhelmed by the higher harmonics, and the bulk of the sound is spread across the [i] first formant resonance at 310Hz, and H3 and H4.

Figure 15: Subject 3, Bb3 (233Hz) full spectrogram, Garcia method

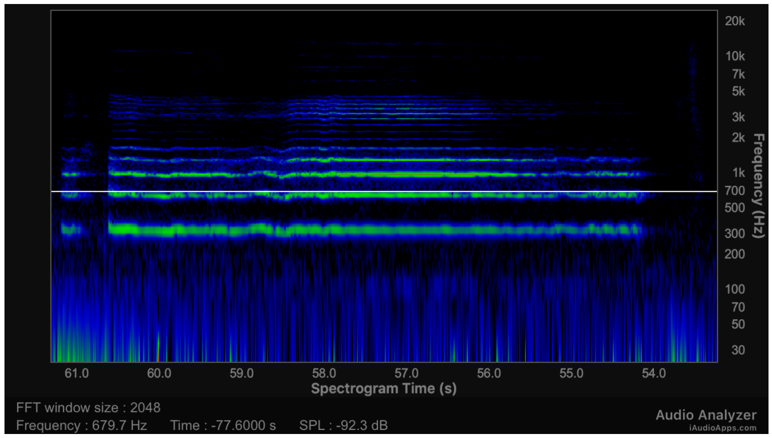
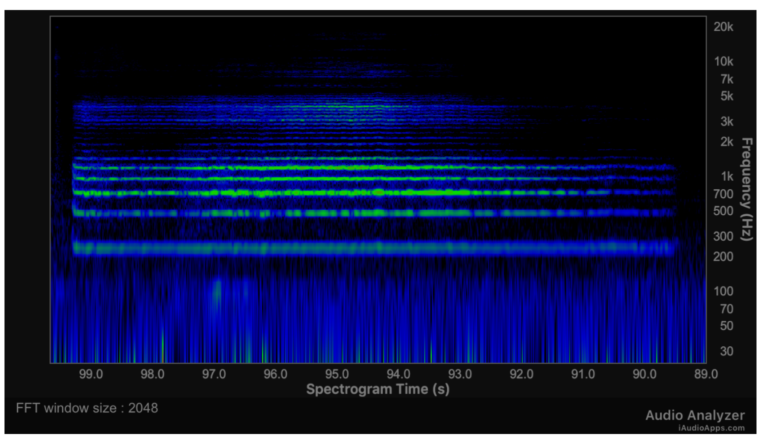


Figure 16: Subject 3, Bb3 (233Hz) full spectrogram, Lamperti method



Moving up the scale to the middle register of the soprano, the next pitch examined is C5 (523Hz). The spectrographs show more similarities than differences, with more intensity apparent in the Lamperti approach and greater spectral slope in the Garcia method (**Figures 17** and **18**). Again, the narrow vibratory frequency displayed in the spectrograms belies the audibly narrow vibrato in the sung tone. H1 and H2 (523Hz and 1047Hz) are available to tune to the vowel formants.

Figure 17: Subject 3, C5 (523Hz) full spectrogram, Lamperti method.

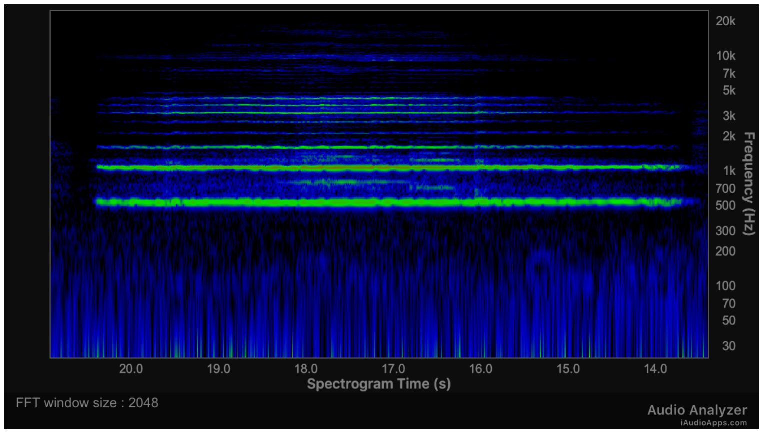
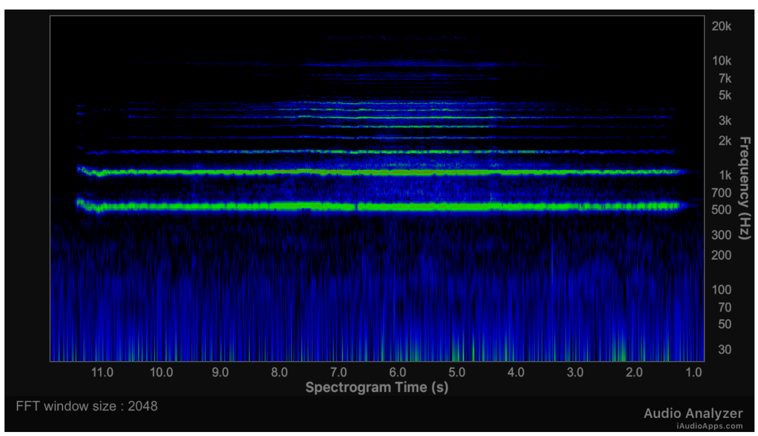


Figure 18: Subject 3, C5 (523Hz) full spectrogram, Garcia method



There is a consistent acoustic strategy in both methods: lowering F1 to pair with the H1 and lowering F2 to pair with H2. The spread of the higher harmonics remains consistent as well. If the formant peaks are removed, the spectral slope is reminiscent of one of an unfiltered tone. The tone sounds white, straight, and narrow. At *forte*, the harmonics begin to separate, and the formants lose their pull, depicted by the greater spread of peaks across the frequency spectrum, and the voice sounds pressed and the [a] vowel blatantly open. There is a strong peak at H6 (3136 Hz) that overtakes the fundamental and provides a ringing quality which mimics the singer's formant cluster. The next frequency analyzed is B5 (988 Hz) near the top of the soprano range. The most striking element of the spectrograms is the intense energy displayed at the fundamental, which happens to pair with both F1 and F2, creating one large formant. This triple boost gives the tone its characteristic brilliant, ringing quality. The full spectrograms are displayed in **Figure 19** and **Figure 20**.

The Lamperti example is notable for the presence of vibrato at *forte*, especially in the higher frequencies. Linearity, slope, and balance are all similar, though the spectrum peaks are much narrower in the Garcia method, displaying much less vibrato. At *forte*, a wide bandwidth at the 1000Hz peak in the Lamperti *forte* carries the bulk of the resonance. There is a general drop off of energy above that. The Garcia approach has a

Figure 19: Subject 3, B5 (988Hz) full spectrogram, Lamperti method

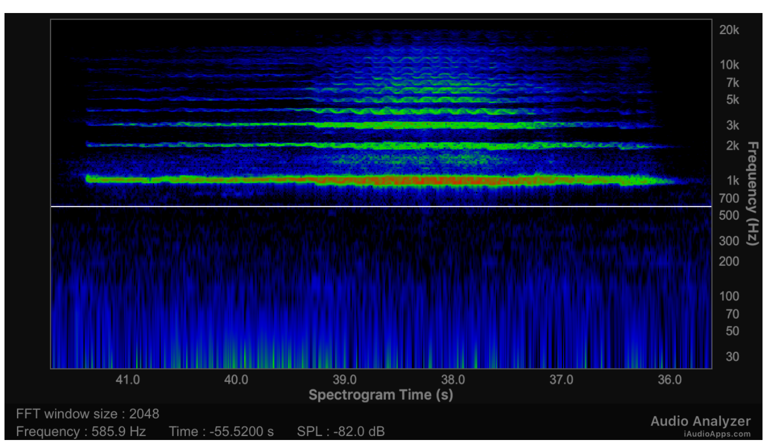
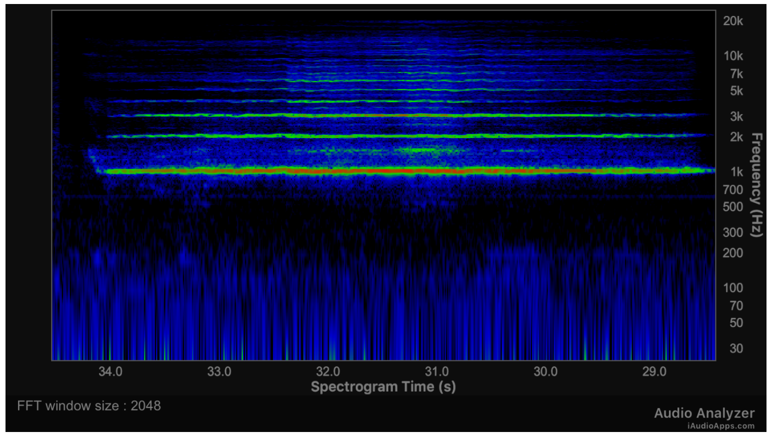


Figure 20: Subject 3, B5 (988Hz) full spectrogram, Garcia method



similar slope but much narrower bandwidths. This is a result of the vibrato-less tone. The limited strategies employed by this subject produced essentially duplicate results. One conclusion can be drawn in being an ear-witness to the recordings: the straighter and thinner the sound, the more isolated the frequency peaks appear. There is much less clustering of partials in a tone devoid of normal vibrato. This produces a tone with fewer spectral colors and less substance.

Subject 4: Tenor

The low pitch for Subject 4 a tenor, is G3. It can be expected for the fourth harmonic (784Hz) to interact with the first formant (730Hz), and the fifth harmonic (1047Hz) with the second formant (1090Hz). There was incomplete glottal closure as Subject 4 began the MDV with the Garcia method, producing a tone void of vibrato until about halfway through its duration and weak in harmonic color (**Figure 21**). When vocal fold closure is achieved the vibrato appears, but the harmonic/formant pairings remain diffuse. Contrast this with the Lamperti spectrogram seen in **Figure 22** which displays a much more organized and regular pattern.

The onset in the Garcia method is characterized by a linear slope downward as the intensity falls off in the higher partials and by the lack of energy in the singer's formant cluster. Finally, at *forte* the resonances within the vocal tract begin to interact more strongly, but only in the area of the singer's formant cluster. The vocal tract is already in

Figure 21: Subject 4, G3 (196Hz) full spectrogram, Garcia method

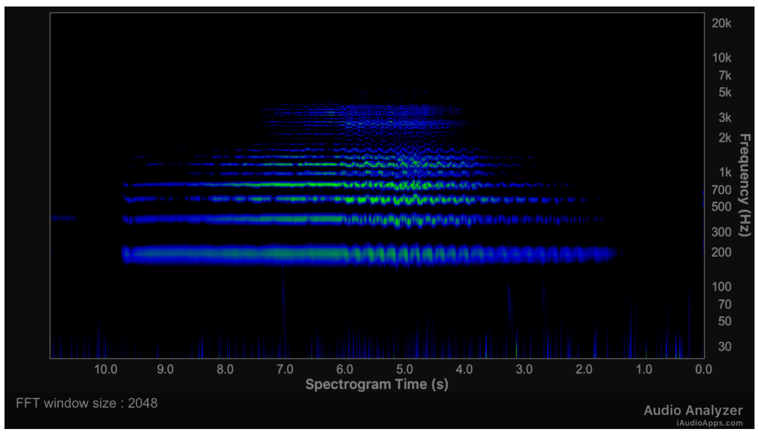
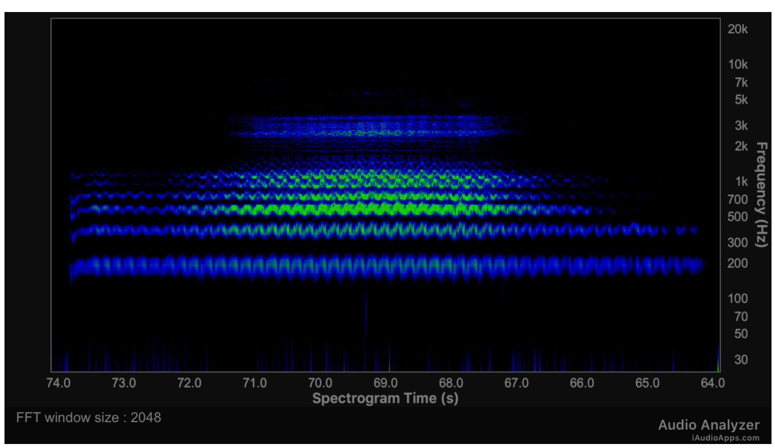


Figure 22: Subject 4, G3 (196Hz) full spectrogram, Lamperti method



balance at the onset of the Lamperti example. The Lamperti crescendo is marked for its high intensity third harmonic. This color of the [a] vowel is darker, approaching [o], and the expected clustering of partials is on display. There is also a strong build-up of energy around 1,000Hz where the fifth harmonic can interact with the second formant. At *forte*, the harmonic boost forces the tone to a second formant dominance: brighter and more constricted in the front of the vocal tract with a lot of clustering above 1000Hz. The two manners of decrescendo display the same interactions and therefore the same fundamental acoustic differences between the two tones. In the Lamperti, the H4/F2 pairing also creates more acoustic energy in the singer's formant cluster range. The Garcia decrescendo almost slopes undisturbed, owing its loss of acoustic energy to the attenuation in the singer's formant cluster.

The middle pitch is near the *primo passaggio* of the tenor, D4 (294Hz). There it can be expected to observe interactions between the H4 (1175Hz) and F2 (1090Hz) for the vowel [a]. In theory, it is a tone that can be approached in a variety of ways. It is tone balanced in head register and *passaggio* and requires flexibility of phonation in the *bel canto* tradition. This tenor shows subtle distinctions in the strategies imposed by the two methods. The Garcia method leads to a strong H4/F2 tone and the Lamperti method is led by the interaction of H2/F1 (587Hz/1090Hz). (**Figure 23** and **Figure 24**). There is also evidentially more space between the intense harmonics in the *forte* tone produced by the Garcia method. This attribute coupled with its particular harmonic formant pairing produces a cleaner more variegated sound. What separates these two examples are their onsets. The Lamperti begins with much more energy in the singer's formant cluster as well as a higher F2, displaying more clarity of vowel as well as a set vocal tract. The

Garcia begins with little energy in the singer's formant cluster but adds it as dynamic is increased. As the crescendo happens, both methods follow a similar resonance path. A notable contrast is the difference in the troughs and peaks between the two graphs. The Garcia spectrograph displays a consistently greater distance between lows and highs. In the Lamperti graph, the disparity is much less, and the clustering of formants is much more intense.

The final note for the tenor is G4 (392Hz), which lies near the *secondo passaggio*. It can be expected to have interactions between H2 (784 Hz)/F1 (730Hz) and H3 (1175Hz)/F2 (1090Hz). As with the D4, this is a tone to be managed with a balance of registration, again between head register and chest register. A comparison of the spectrograms reveals key differences between the two methods (**Figure 25** and **Figure 26**). The greater spectral slope lies with the Garcia approach, whereas the Lamperti method provides ringing tone from onset to release and a reduced dynamic envelope.

Figure 23: Subject 4, D4 (294Hz) full spectrogram, Garcia method

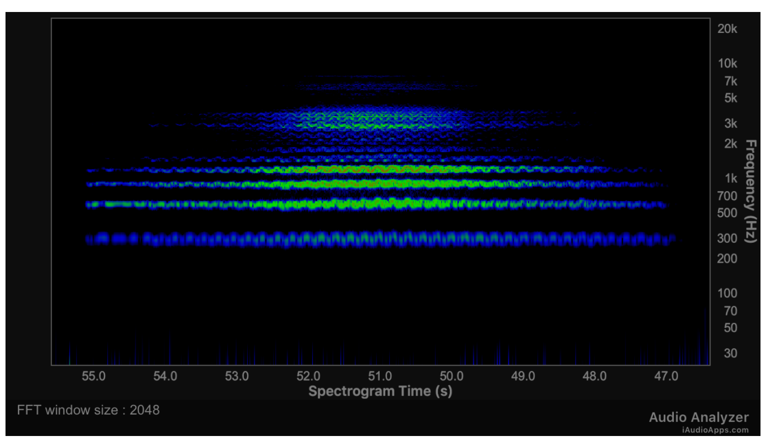
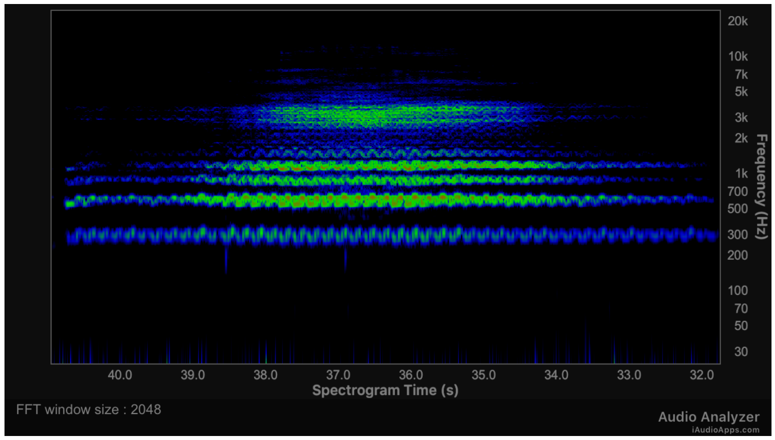


Figure 24: Subject 4, D4 (294Hz) full spectrogram, Lamperti method



There are also two binary shifts of muscular activity with the Garcia method caused by modulating the degree of glottal closure. As the Lamperti method calls for consistent closure there is no need to manage such a muscular adjustment. An examination of the onsets reveals a first formant dominance for Garcia's method and a balanced vocal tract onset for Lamperti's method. The decibel difference is negligible, but the presence of the singer's formant cluster in the Lamperti example greatly increases the acoustic energy.

Figure 25: Subject 4, G4 (392Hz) full spectrogram, Garcia method

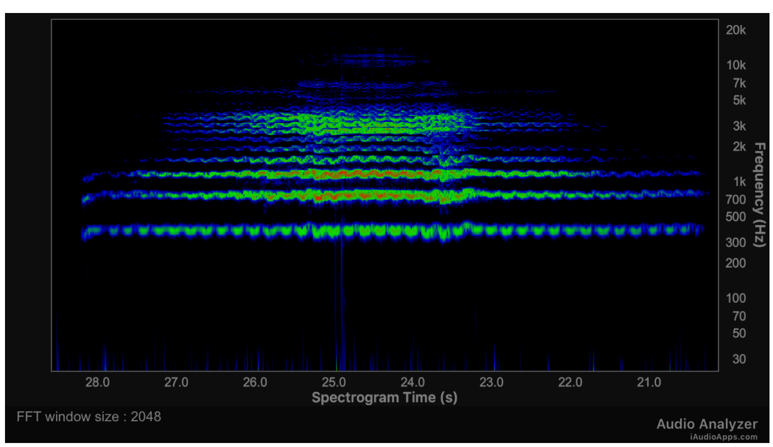
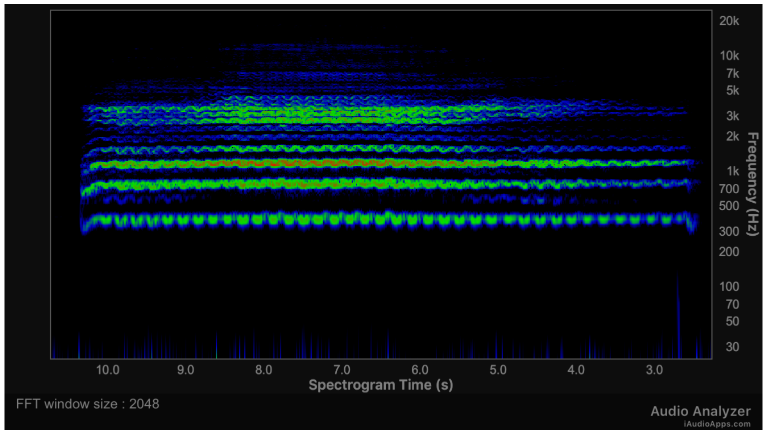


Figure 26: Subject 4, G4 (392Hz) full spectrogram, Lamperti method



At *mezzo forte*, the Garcia tone has assumed well-balanced acoustic energy across the frequency range. The Lamperti example shows the H3/F2 acoustic pairing, which lightens the load on the mechanism and closes the vowel. The acoustic profiles vary in their relation of fundamental to partials. The Garcia method is dominated by the second formant. At *forte* its peak is thirty-five decibels higher than the fundamental, the F2/H3 taking intensity away from their upper neighbor, the fourth harmonic. The sound is clear and high.

The Lamperti method produces a tone with significantly more fundamental and stabilizes the vocal tract. It maintains its acoustic resonance strategy of the H3/F2 pairing and energizes the frequencies above 1000Hz. The decrescendos exhibit the same tendencies as the crescendos. The Garcia decrescendo is achieved by a drop in acoustic energy in the partials above 1000Hz. The Lamperti method is managed by a separation of lower partials and a general drop in amplitude governed by the *lutte vocale*.

Comparison

The utility of the Audio Analyzer application produces remarkably clear data that can be saved to analyze for easy reference. This attribute, along with the ability to see the spectral balance in real time in order to make immediate adjustments to the vocal tract, is immensely practical. In this study, the main differences between the two methods are observable in the onsets and control of the resonance intensities in the singer's formant cluster. The Lamperti onsets are distinguished for their tendency to create a stable vocal tract. **Table 1** shows the height of the singer's formant cluster at onset for all subjects. The Lamperti onsets have a higher amplitude than the Garcia onsets. The Garcia onsets are characterized by the lack of energy in the singer's formant cluster. **Table 2** displays the amplitude of the singer's formant cluster at *forte* for all subjects. These results were more variable. There was no correlation between height of singer's formant cluster at onset and at *forte*. **Table 3** displays the difference in amplitude of the singer's formant cluster between the onsets and *forte* for all subjects. The data displayed shows a greater excursion of amplitude from onset and *forte* in at least one register for three of the subjects. Subject 3 did not produce an optimal spectral balance in her samples. The tone can be described as pure, lacking in vibrato, with a clear separation of partials evident in the power spectra. There is little or no clustering of harmonics to create a balanced *chiaroscuro* tone. The greatest disparities occurred in Subject 1's chest register. There was a difference of 28 decibels between the Garcia method and the Lamperti method, and in Subject 2's head register: a difference of 30 decibels between the methods. The male subjects showed a more consistent variation in amplitude between the two methods. This is consistent with the fact that due to the lower fundamental frequencies of their samples, more partials are available to tune to the vowel formants.

Table 1: Amplitude of the singer's formant cluster at onset (estimated measurements taken from power spectra).

	Garcia method			Lamperti method		
	chest	middle	head	chest	middle	head
Subject 1	-80dB	-90dB	-72dB	-72dB	-80dB	-60dB
Subject 2	-92db	-88dB	-96dB	-84db	-80dB	-64dB
Subject 3*	NA	NA	NA	NA	NA	NA
Subject 4	-96dB	-102dB	-86dB	-76dB	-80dB	-58dB

*Collected data were not applicable for measuring the singer's formant cluster due to the high fundamental frequency

Table 2: Amplitude of the singer's formant cluster at *forte* (estimated measurements taken from power spectra).

	Garcia method			Lamperti method		
	chest	middle	head	chest	middle	head
Subject 1	-44dB	-46dB	-32dB	-54dB	-54dB	-32dB
Subject 2	-38dB	-26dB	-40db	-34dB	-38dB	-38dB
Subject 3*	NA	NA	NA	NA	NA	NA
Subject 4	-46dB	-40dB	-26dB	-48dB	-32dB	-32dB

*Collected data were not applicable for measuring the singer's formant cluster due to the high fundamental frequency

Table 3: Difference in amplitudes at onset and *forte*.

	Garcia method			Lamperti method		
	chest	middle	head	chest	middle	head
Subject 1	-46dB	-44dB	-40dB	-18dB	-26dB	-28dB
Subject 2	-54dB	-42dB	-56dB	-50dB	-42dB	-26dB
Subject 3*	NA	NA	NA	NA	NA	NA
Subject 4	-50dB	-62dB	-40dB	-28dB	-48dB	-26dB

* Collected data were not applicable for measuring the singer's formant cluster due to the high fundamental frequency.

Interviews: Singer Sensations and Feedback

Interviews were conducted alongside the recording of the data samples and recorded via the Audio Analyzer application. They consisted of guided discussions particular to the individual. The interviews revealed that none of the subjects were familiar with the term *messa di voce* or its use as a vocal exercise. Their experience with their voices allowed them to tackle the maneuver with a good measure of finesse and expertise. When asked which of the two methods were easier to execute, all subjects replied that the Lamperti method was easier. A reason for this could be that the general acoustic balance seen in the onsets, crescendos, and decrescendos in the graphical data during the Lamperti exercises, is a result of consistent glottal closure throughout the tone which provides a sense of stability or *appoggio*. Three mentioned a sensation of more bodily connection while executing the MDV according to the Lamperti method, while the Garcia method involved a more delicate balance of respiratory forces and phonatory mode. One subject mentioned that the Garcia method required more concentration. One subject mentioned the advantage of having the ability to do both. All subjects agreed that the MDV is a useful exercise to train the complete instrument. This leads to the conclusion that the Lamperti method would be the best choice to introduce the MDV to a beginning student. The Garcia method is better be left to the more advanced student with its more delicate balancing of forces. I would also suppose that particular voices are attracted to one method or another.

Discussion

The historical method of training the voice involved daily lessons with one's teacher. This allowed the master to guide the student's progress efficiently and completely. We no longer engage in this kind of training, usually seeing a student only for an hour once a week. For the remaining time the student is left on their own, to work out how to sing by internal listening and physical sensation, which are unreliable for a beginning singer. Teachers often insist that students make audio recordings of their lessons. While this is helpful, it still places most of the burden of progress on the students' limited ability to hear a properly balanced tone. Employing means to see the sound produced on the frequency spectrum is helpful, allowing the visual to inform the aural. The Audio Analyzer application used to record and analyze the samples proved to be incredibly useful at seeing the harmonic activity within the vocal tract in real time. The informed teacher can then reinforce the desired aural quality by referring to the spectral image of the properly sung tone, which in the *bel canto* tradition is one that produces a particular balance of fundamental frequency, vowel formants, and singer's formant cluster. This is a tone with a bright ring at its core within a dark shell, known as *chiaroscuro.* Knowing what to look for can guide what to listen for, thus the student can exercise the voice more efficiently, ostensibly making progress with less unnecessary wandering.

The goals of this study included a direct comparison of the harmonic spectral prints of two differing historically informed approaches to the *messa di voce* exercise. Three seasoned professional *bel canto* trained singers and one young professional trained in the *bel canto* tradition provided the data that was analyzed. Three pitches from three distinct parts of their respective ranges were recorded. The analysis revealed significant differences in the two methods only at fundamental frequencies below C5. The most frequency change occurred in the area between 1000Hz and 3000Hz, especially in the upper end, i.e. the singer's formant cluster. This frequency band coincides with the peak of Tomatis' listening curve of the musical ear (**Figure 4**). Following Garcia's method produced the greatest excursion of amplitude in this region due to its weakness at the onset and in any dynamic below *mezzo forte.* This frequency range varied most along the spectral slope, increasing with the crescendo and decreasing with the decrescendo. The malleable nature of the Garcia approach induced changes in the vocal tract as the dynamics changed. In pitches below C5, the Lamperti dynamic changes were most often displayed as a balanced increase of energy across the spectrum, with particular emphasis on the vowel formant region. Here, vowel formant tuning to available harmonics was most apparent. This coincides with the subjects' descriptions of greater definition and clarity of the vowel during the crescendo in the Lamperti method. The male voices especially employed formant tuning in managing pitches in and around the *passaggio*. Two other important harmonic elements to the tone, the fundamental frequency (the pitch being sung) and the area of the singer's formant cluster (approximately 3000Hz), balanced intensities across the dynamic change during the exercise.

To examine their harmonic profiles is to see the flexibility in resonance tracking that occurs in the Garcia method as opposed to the more fixed acoustic balance of the Lamperti method. As one singer described, one technique would be useful singing Handel and the other while singing *verismo*. Other differences between the two methods seemed to be isolated to the individual, such as vibrato and linearity. The Garcia method produced graphs exhibiting variable behavior of acoustic energy. The onsets led by the fundamental indicate a thin edge vibration of the vocal folds, Garcia's falsetto. The physiological adjustment that must occur in order to gracefully pass through the registers and manage dynamics, maneuvers the vocal tract in ways that produces more changes in the spectral balance. The singer's formant cluster was more reactive in the Garcia method. Its intensity often surpassing that of the fundamental at *forte*. Although the data gathered from Subject #3 was not useful in analyzing the singer's formant cluster during the MDV due to the high fundamental frequencies and lack of available upper partials, the separation between the harmonics, the lack of clustering visible in the spectrograms and power spectra provides good evidence of a whiter, more "pure" tone.

Conclusion

What began centuries ago as a simple, musically expressive crescendo-decrescendo has become a device to measure a singer's skill at balancing the vocal instrument. The *messa di voce* has been used in voice science research to measure such things as subglottal pressure, airflow rates, and long-term average resonances. Real-time spectral analysis measures vocal tract modifications through corresponding changes in the frequency spectrum. The two historically informed approaches to singing a *messa di voce* produce divergent graphical results. In the *passaggi* where register balance is most crucial, the aural effects are strikingly different as well. The Garcia method tended to control dynamics by modulating intensity within the singer's formant cluster. This produced a sound with a bright core within a dark shell. The Lamperti method most often tuned H3 to F2 to boost the vowel's second formant, but in relative balance with the fundamental and other partials. This produced a sound that was clear and bright, more connected, more *appoggiata*. Both approaches produce sounds that are viable and useful for producing a full palette of colors with one's voice. As mentioned earlier in the paper, the sounds and approaches seem suited to particular repertoire. It is difficult to imagine a satisfying performance of a Bach aria, a Schubert lied, or even the Countess' "Porgi amor" from *Le nozze di Figaro* without flexibility and nuance as pillars of the vocal posture. Whereas it can be disappointing to hear the dramatic operatic repertoire sung without the proper stability and consistent ring in the tone. Of course, these are generalities, as there are no absolutes in the vocal arts, and great artists transcend many limitations.

Both the method attributed to Manuel Garcia II and the method attributed to the Lampertis are shown to be valid manners of approaching the MDV. This study shows that the Lamperti method would be most useful in training beginners due to its fewer moving parts. However, it would be logical to exercise both approaches to train balance of phonation in the muscles of the larynx, respiratory control, and vocal tract posture. The Audio Analyzer application by iAudioApps for measuring and recording the resonances of the vocal tract on the frequency spectrum in real time is shown to be quite useful in ensuring proper balance of harmonics and formants and is easy to use. It has shown that two different ways of singing a *messa di voce* can produce different onsets, different modes of phonation, different vocal tract postures, and different acoustic profiles.

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